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Agricultural Memorandum No 917

Animal Housing Ventilation Studies by J R Starr.

Introduction

In order to achieve the optimum productivity from housed livestock it is generally acknowledged that the thermal comfort of the creature is of prime importance implying that the environment should be adequately controlled by fan ventilation or natural means so that 'thermo-neutrality' is maintained under a wide range of meteorological conditions. (Smith 1971, Starr 1981). Adequate air-change rates are also important if the build-up of harmful pathogens is to be minimised (Roe 1980, Webster 1981). Suitable ranges of animal housing environment factors are quoted (eg Mitchell 1976) but these are not sufficient in themselves to ensure an equable environment; air-flow trajectories should be investigated to ensure that appropriate air-change rates have not been achieved by excessive ventilation of part of the housing volume at the expense of other critical regions (particularly at animal level).

This memorandum reports several investigations in both naturally-ventilated and fan-ventilated houses illustrating some of these points.

Investigations

Smith (1973) and Adams (1977) report air-change rate investigations in animal housing using an infra-red gas analyser and the tracer gas NO_2.

Briefly, one estimate of the local air renewal rate at the sampling point is given by the total time for the measured gas concentration to fall from a peak value C, at time t_1, to a unit value C_2 at t_2. This time includes re-circulation delays to the decay rate.

The average rate, N changes/hr is given by:

$$N = \frac{138.2\ (\log_{10} C_1 - \log_{10} C_2)}{t_2 - t_1 \text{ (minutes)}}$$

(Note: if $C_2 = \frac{C_1}{2}$ after a time $t_{1/2}$, $N = 41.6 \Big/ t_{1/2}$)

(assuming perfect mixing and exponential change of concentration). Peak values of N can be found over short periods in every situation.

The integral $\int_{t_1}^{t_2} c\,dt$ is given by the area under the concentration x time curve and the integral $\int_{t_1}^{t_2} c.tdt$ may be estimated from the summation $\sum_{t_1}^{t_2} c.\Delta t.t$.

The residence time: $$\bar{t} = \frac{\int_{t_1}^{t_2} ct.dt}{\int_{t_1}^{t_2} c\,dt}$$

and the ventilation rate $R = \frac{1}{\bar{t}}$, the rate of removal of fresh inlet air.

The ratio R/N over the sampling period may be interpreted as the percentage of the local air renewal rate allocated to the arrival of fresh inlet air, the remainder to recirculated air. (The assumption of perfect mixing of the tracer gas and inlet air may <u>not</u> be met for open, naturally ventilated houses).

The gas analyserused by Smith & Adams was cumbersome to transport and required a fair amount of skill and patience in operation. A more compact device (Model 505), simple to operate, has recently become available through AI (Analytical Instruments) Ltd. It used Sulphur Hexafluoride (SF_6) as the tracer gas and as originally envisaged, I gather, was developed as a sensitive detector of leaks from pipes. The response is linear on ranges 1, 2 and 5 (ppm) but significantly non-linear on ranges 10, 20 and 50.

Readings were commenced at minute intervals soon after the introduction of the SF_6 gas but many minutes transpired in large volume housing before the concentration had decayed to allow readings to be made on the '5' range. (The pointer was zeroed at the beginning of each reading).

Air-flow trajectories were established at inlets and outlets by a smoke puffer and the corresponding speeds measured with a hot-wire anemometer, suitably shielded on a short tube so that only motion perpendicular to the plane of the orifice was registered. These measurements together with dimensions of all appropriate orifices enabled a balance sheet of inlet and outlet flow values to be drawn up. These procedures must be done thoroughly so that air-change rates, measured by the gas analyser, may be interpreted as volumetric in- and out-flow in various parts of the housing.

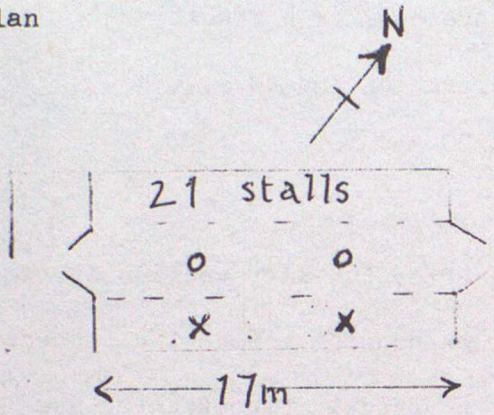
Ventilation surveys

A. Crown Farm, Ascott-under-Wychwood, Oxon. 25 September 1980.

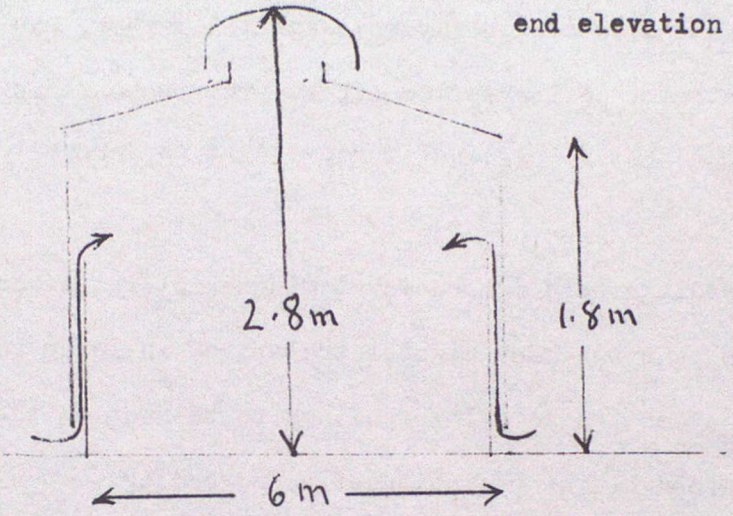
Pneumonia had been a problem in the building which was designed for 42 calves, going in at about 36 kg (4 days) and out at between 68 - 91 kg. The building, recently constructed by a local builder, appeared to be two mono-pitched

structures facing each other with a curved roof spanned between them. Overall dimensions were approximately: 17 m long, 6 m wide, 1.8 m to eaves 2.8 m to curved ridge.

Plan



end elevation



At one end: two sets of doors (with office space between) at the other, stable type doors, upper halves opening.

The equipment was loaned by the Farm Buildings Group and Mr D Hughes, Senior Buildings Services Engineer, advised on its use. He was assisted by the Met Officers in making the SF_6 and the wind flow measurements.

Meteorological Conditions

An anticyclone centred over N E England gave light winds with generally a south-westerly component. Insolation was strong during the 4-hour period of measurements a maximum temperature of 18.0°C being attained. By 1200Z the outside air temperature was 16.5°C and wet-bulb 12.4°C (RH : 62%). Within the house, with closed doors, the temperature at calf head height varied from 20.8°C within occupied stalls (x) to 21.5°C in the inter-stall central gangway (o) (see sketch). Corresponding RH's were 62% and 58%.

All these measurements were made at points $\frac{1}{3}$ and $\frac{2}{3}$ the way along each side (see sketch plan).

Air flow measurements

Experiment 1: All doors closed.

a) Eaves inlets:-

Dimension of inlet at point of measurement

= 70 mm wide

= .07 m

Wall length of each cubicle = 0.794 m

and 21 cubicles

∴ total length = 21 x 0.794

= 16.674 m per side

less framework of 2 x 50 mm obstructions in every pen

= 21 x 2 x 50 mm = 2.1 m per side

∴ actual opening = 16.674 - 2.1 = 14.574 m per side

= 29.15 m total

∴ eaves inlet area = 29.15 x .07

= 2.04 m^2

Average inlet velocity recorded = 0.105 m/s

∴ inlet air quantity = 2.04 x 0.105

= 0.2142 m^3/s

= 771 m^3/h

b) Ridge Outlets:- Generally it was very difficult to record what was happening at the ridge. The results can only be considered as a rough guide.

Assume that sections with air flow both in and out cancel each other out (ie wind blows straight across the top with little or no effect on the house ventilation).

Area of each section measured = 0.794 x 0.2

= 0.1588 m^2

28 sections flowing out at average velocity

= 0.291 m/s

$\therefore$ total used outlet area = 28 x 0.1588

= 4.4464 m^2

$\therefore$ outlet air quantity = 4.4464 x 0.291

= 1.29 m^3/s

= <u>4658</u> m^3/h

Similarly:

5 sections flowing in at average velocity

= 0.283 m/s

$\therefore$ total used inlet area = 5 x .1588

= 0.794 m^2

$\therefore$ inlet air quantity at ridge = 0.794 x 0.283

= 0.225 m^3/s

= <u>809 m^3/h</u>

c) Gaps around door:-

Inlet under door 0.1 m^2 at 0.95 m/s

= 0.095 m^3/s

= <u>342</u> m^3/h

Outlet above door = 0.2 m^2 at 0.2 m/s

= 0.04 m^3/s

= <u>144 m^3/h</u>

Summary of anemometer readings:

Total inlet as recorded = 771 + 809 + 342 m^3/h

= 1922 m^3/h

Total outlet as recorded = 4658 + 144

= 4802 m^3/h

Conclusions of anemometer readings:

There obviously cannot be more air leaving the building than coming in. It seems likely that the air was blowing about in all directions at the ridge an in fact more air was being blown in (as opposed to out) than was actually measured.

Air being blown around at the ridge and coming in under the doors would have little effect at calf level. It would therefore seem not too unreasonable to consider that the <u>useful</u> flow rate through the building would be the 771 m^3/h entering at eaves level, and an <u>actual</u> flow rate through the building of 1922 m^3/h.

Experiment 2: Doors opened

Inlet through 2.45 m x 1.00 m at 1 m/s

= 2.45 m^3/s

= <u>8820 m^3/h</u>

Outlet through 2.03 x 1.03 at 1.2 m/s

= 2.51 m^3/s

= 9033 m^3/h

These readings appear to support each other and a ventilation rate of about 9000 m^3/h can be assessed, although air distribution under these conditions will not be very good.

<u>SF_6 Detector Results</u>

See result sheet

From result sheet ($t_{\frac{1}{2}}$) half life = 140 seconds on range '5'

Room volume = 16.674 m x 5.78 m x 2.3 m (average height)

= 221.66 m^3

$\therefore$ N = $\frac{221.66 \times 0.693}{222}$

= <u>2491 m^3/h</u>

This figure compares reasonably with the total inlet figure recorded with the anemometer.

Summary of Results m^3/h

	Useful ventilation rate at calf level	Actual ventilation rate
Anemometer	771	1922
SF_6 Detector	-	2491
Recommended minimum summer ventilation rate based on $105 m^3/h$ per calf place	4410	

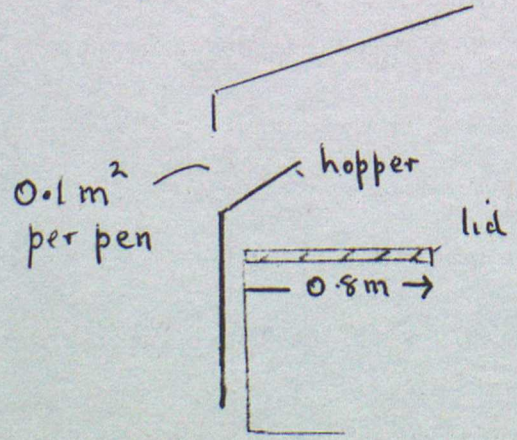
Comments

1) The set of readings on the gas detector (range 5) is within 25% of the anemometer inlet readings.

2) The recorded minimum ventilation rate in the above table is a figure which is usually related to fan ventilated calf buildings. Specifications for naturally ventilated buildings are usually in terms of areas of openings which have been found to work. The openings on this building are much lower than would normally be recommended.

3) An acceptable solution suggested by Mr Hughes would be to open up holes in the side walls together with a continuous plywood hopper arrangement which will keep out the worst effects of wind and rain. One hole of about 0.1 m^2 per pen would be best but one hole of twice that area for every two pens would be acceptable. The hopper would 'spread' the air from the openings. It is also important to have 'lids' on the back of the pens to offer some individual protection for the calf.

eg.



4) The average ventilation with the doors open is about 9000 m^3/h. This is clearly enough air but the distribution will be poor, with the possibility of draughts, particularly for the animals near the entrance door which is where the air enters. As an interim measure perhaps the far half-door could be open and/or some animals moved away from the first 2 or 3 pens near the entrance door.

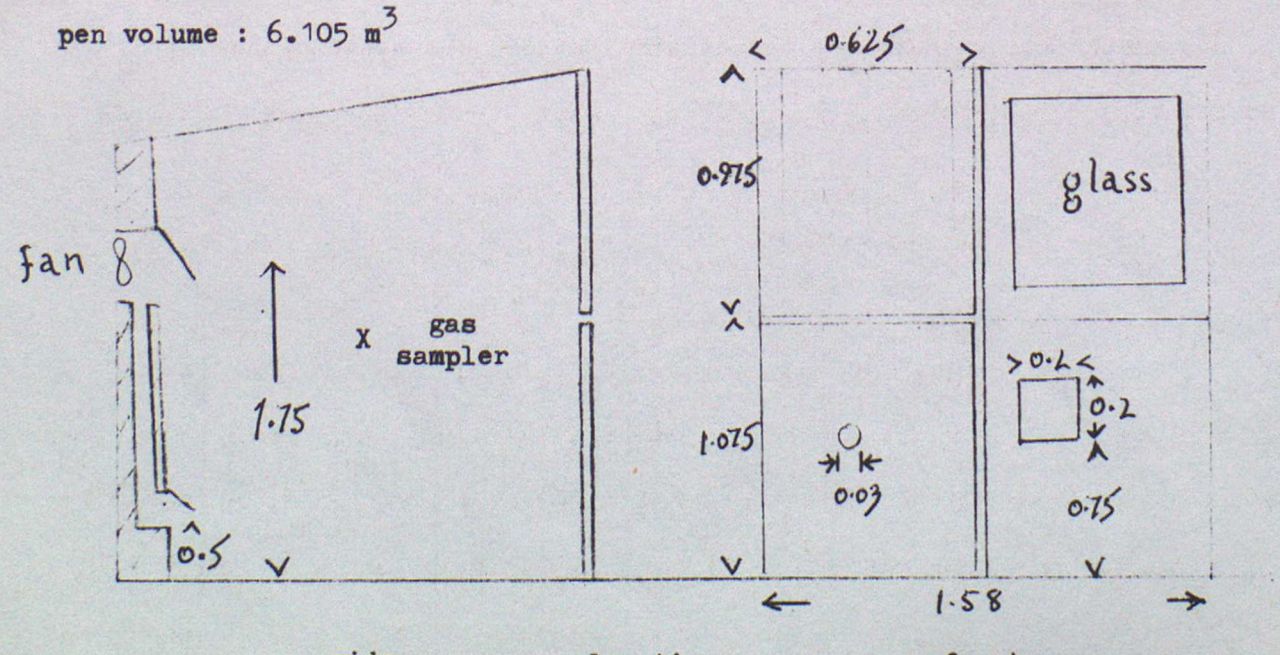
B. Individual calf pens at Central Veterinary Laboratories, Weybridge. 1 Dec 1980

As part of an investigation into the aetiology, and pathogenesis of calf pneumonia disease carried out by Mr Edwards and Miss Lucas of CVL, pneumonia virus was 'introduced' into calves which were then housed in individual units.

The SF_6 gas analyser was operated at two of these pens on 1 December 1980.

The calves were isolated in eight similar pens in a long block. Each pen was roughly of dimension 2m x 2m x 1.5m (width) and was accessed by means of a 'halved door'. A fan in the back wall extracted air via two gratings each of 400 cm^2 area 1.5m vertically apart. The pen is sketched below (dimensions in metres).

pen volume : 6.105 m^3

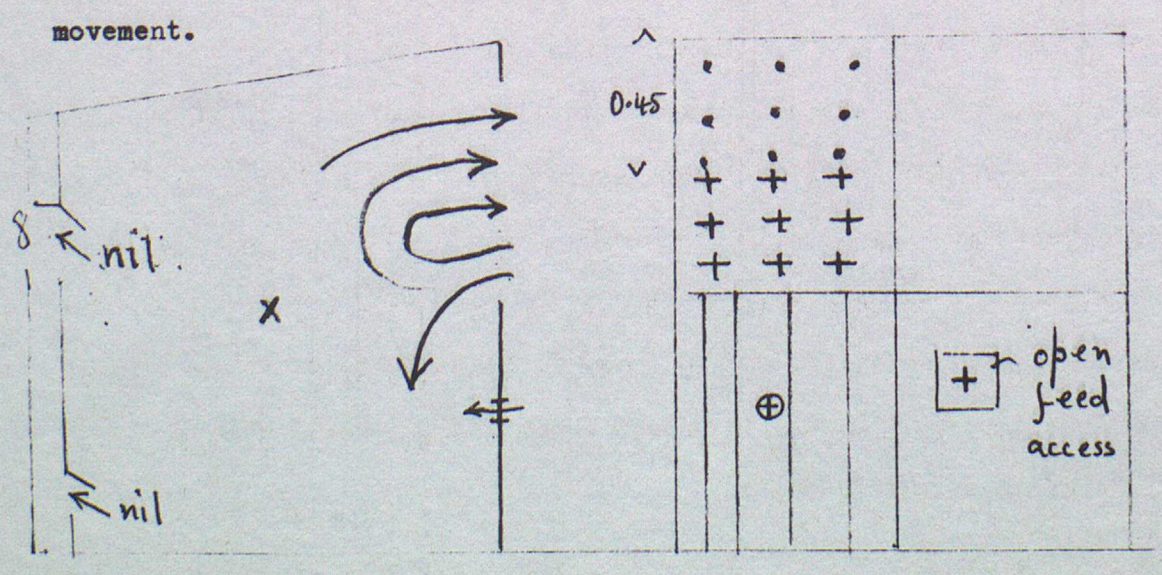


Two ventilation rate studies were performed (both with a calf 'in situ') one with the pen in its usual 'state' during the pneumonia study, that is with the top half-door open and no fan extraction. For the other study, in another pen, doors and other orifices were closed, ventilation being supplied by fan; in both cases two 'heating lamps' were on. During the studies (under calm conditions) the outside temperature did not rise much above 0°C.

i. Open door study

With doors and orifices shut and the SF_6 sampling tube in position just above calf nose height, the SF_6 gas was introduced , mixing being encouraged by manually fanning with a piece of card through the slightly opened half-door. After several minutes the top half-door and the food orifice were opened, and gas sampling was commenced at one minute intervals. The other operator, using the smoke puffer, traced the general pattern and 'sense' of the air movement in and out of the house (as well as the circulation pattern inside). Then with a hot-wire anemometer the average speeds were measured at right angles to the orifices.

The sketch below indicates the general pattern and sense of the air movement.



Key: airflow • out, + into pen

Volumetric analysis

	Orifice	area m^2	av. speed ms^{-1}	volume $m^3\ s^{-1}$	Total m^3/s	Total m^3/hr
IN	'door'	0.281	0.8	0.223	0.255	918
	'feed' hole	0.04	0.8	0.032		
	hole in door	7×10^{-4}	0.3	2.1×10^{-4}		
OUT	'door'	0.3281	0.75	0.246	0.251	904
	vent, hole	0.046	0.1	0.005		

SF_6 analyses:

N = 25.7/hr = 157 m^3/hr

R = 23.9/hr

$\frac{R}{N}$ = 93% (i.e. 93% of the local air renewal rate is due to the arrival of fresh, inlet air)

at 14 30 z

Outside pen : av. temp 2.0°C , RH = 80%

Inside pen : av. temp 4.8°C , RH = 58%

Comments

There is a large difference between the in and out air flow estimated for the volumetric analysis and that derived from the SF_6 analyser data the latter being apparently less than $\frac{1}{5}$ of the former. The 'in' and 'out' flow estimates are self consistent hence we may assume that these studies are not greatly in error, rather there is considerable air change occurring locally at the open half-door the effect not penetrating deeply into the housing (although there is no lack of fresh air at the sampler).

ii Closed door study; ventilation fans on

Equipment was set up in an adjacent pen to that used in study i. Air inlets were now well defined as the cracks round the door and the hole in the bottom door while the outlet was through the one ventilation hole. Because the fan orifice was circular and the ventilation outlet square with 6 horizontal louvres the outlet volume was estimated from the average velocity across each rectangle defined by the louvres.

Volumetric analysis

Orifice	Area cm^2	velocity m/s	volume m^3/s ($\times 10^{-3}$)
Upper door			
top	1.1 x 62.5	1.2	8.25
sides	0.6 x 97.5	0.5	2.925
"	0.6 x 97.5	1.2	7.02
bottom	0.75 x 62.5	0.2	0.94
Lower door			
sides	2 x 0.5 x 110	0.2	2.20
bottom	0.2 x 62.5	0.1	0.12
hole	7.07	1.7	1.2

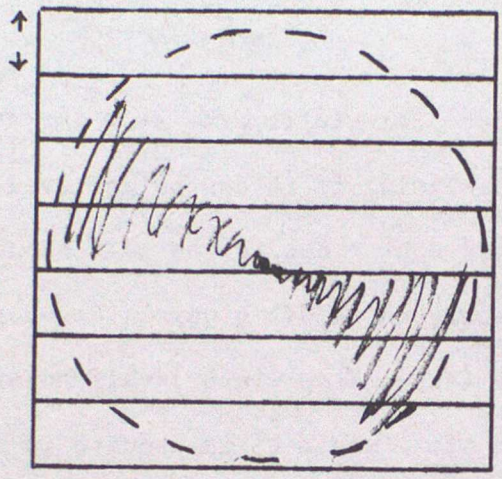
in

Total 22.7

= 81.6 m^3/hr

Small errors in measuring the average width of the cracks round the doors could lead to errors of 10-20% in the estimated of air-flow.

Volumetric measurements at the only fan exit offered the possibility of accurate air-flow studies.



Average depth cm	Average velocity (m/s)	Volume outflow ($m^3/s \times 10^{-3}$)
5	0.1	1.075
3	0.3	1.935
3	1.3	8.385
3	0.3	1.935
3	0.4	2.580
3	0.7	4.515
1	2.5	5.375
		25.800

Volume out = 92.9 m^3/hr

Velocities averaged across the internal upper and lower inlet gratings were about 0.8 and 0.1 m/s respectively indicating that low level (0.5 m above the floor) air movement was likely to be sluggish - as indeed smoke-tracers confirmed.

<u>SF_6 analyser</u>

N = 15.1/hr = 92 m^3/hr

R = 9.8/hr

$\frac{R}{N} \equiv 65\%$

[at 15 30 z : outside pen : av. temp = 1.5°C , RH = 80%
inside pen : av. temp = 6.0°C , RH = 70%]

<u>Comments</u>

Good agreement was (fortuitously?) found between air-change rates estimated by the gas analyser and by volumetric study.

Summary

Mitchell (1976) comments on the functions of ventilation in maintaining a suitable calf environment: during the winter excessive air movement around calves has to be avoided but when calves are housed in the warmest months a high ventilation rate is required to keep down house temperatures.

Recommended minimum (fan) ventilation rates for winter are 34 m^3/hr and in summer 105 m^3/hr (though up to 205 m^3/hr may be beneficial if it can be achieved without causing draughts). It appears that air movement close to the calf should not exceed 0.25 m/s in winter; this was not achieved in CVL study i, although the air change rate was acceptable for summer (as well as winter) calf housing. The study ii showed that fan ventilation alone would be inadequate in summer with the doors closed.

Acknowledgements

The co-operation of the Farm Buildings Unit, Coley Park is gratefully acknowledged, and particularly the assistance of Mr D Hughes. Some of Mr Hughes calculations are presented in the Ascott - u - Wychwood results. I am grateful also to Mr Edwards and Miss Lucas for allowing access to the CVL calf-housing, Mr Badger for his co-operation at Crown Farm and to Mr C P Roe of this office for his assistance.

All comments and suggestions to be referred to the author.

Meteorological Office
MAFF Coley Park
Reading

June 1981

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RESULT SHEET

SITE: Crown Farm, Ascott - u - Wychwood. 25.9.80

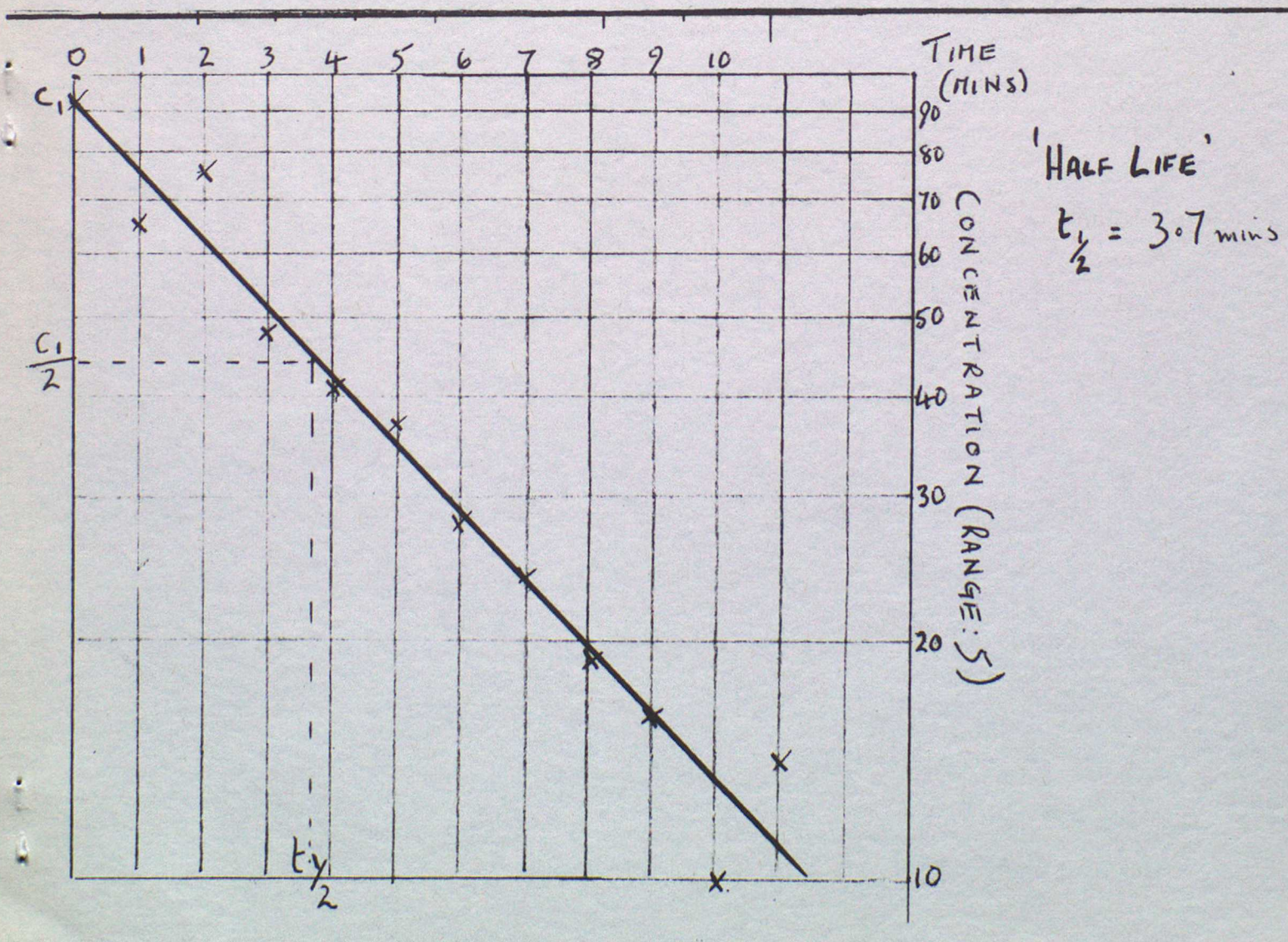
HOUSE VOL: 221.66 m^3

$$Q = \frac{V \times 0.693}{t_{\frac{1}{2}}} = 2491\ m^3/l$$

(11.2 V)

RANGE 20 10 5 2

t	c	t	c	t	c	t	c	
0	64	0	60	0	81	0	34	
1	67	1	66	1	65	1	31	
2	48	2	57	2	76	2	17	
3	67	3	71	3	48	3	22	
4	-	4	32	4	41	3	15	
5	62	5	47	5	37	5	13	
6	50	6	50	6	28	6	13	
7	46	7	56	7	24	7	8	
8	52	8	57	8	19	8	6	
9	23	9	33	9	16	9	8	
		10	36	10	10			



'HALF LIFE'

$t_{\frac{1}{2}} = 3.7$ mins